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# MULTIPIXEL LIQUID CRYSTAL DISPLAY

mm917 The Present invention relates to a multipixel liquid crystal display having a liquid crystal cell and polarizers ~~according to the preamble of Claim 1~~.

mm927 ~~Background Information~~

Liquid crystal displays have become known in different embodiments. STN and TN liquid crystals are most frequently used. STN stands for Super Twisted Nematic and TN stands for Twisted Nematic.

Twisted Nematic means that a twisted nematic liquid crystal phase is used.

The design of a conventional TN display is illustrated in Figures 3a and 3b. A liquid crystal is sandwiched between two glass plates, each of which is coated with a transparent electrode. The liquid crystal molecules are indicated as elongated rods. The liquid crystal molecules are oriented ~~helically twisted by 90°,~~ using an orientation layer, so that they are arranged between the substrates. Polarization filters, whose preferred direction of transmission is indicated by a double arrow in ~~Figure 3~~ Figures 3a and 3b, are applied to the outside of the glass plates. The polarizer is located on the side of incidence of light, and the analyzer is located on the side where the light exits. In the voltage-free state of the cell illustrated in Figure 3a, polarized light enters, is twisted by 90° due to the 90° liquid crystal molecule helix and can exit through the analyzer. Liquid crystal displays that are transparent in the voltage-free state are known as "normally white" displays. If a sufficiently high voltage is applied between the electrodes, the liquid crystal molecules align themselves parallel to the electric field, whereby the incident light remains essentially unaffected and is therefore absorbed by the analyzer. In this state the liquid crystal display is dark. In a normally white display, light transmission decreases continuously with increasing voltage. Thus a certain transmission and therefore a gray value (gray level) can be uniquely assigned to a given voltage. In conventional liquid crystal displays, however, transmission and thus the gray level are dependent on the viewing angle. The viewing angle can be uniquely represented using polar coordinates as Figure 4 shows.

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Thus angle φ in the plane of the display assumes values from 0 to 360°. Angle θ has a range of values from 0 to a maximum of 90° and shows to what degree the viewing angle is inclined in relation to the normal to the liquid crystal display. Figure 6a shows transmission a as a function of inclination angle θ for φ = 0° and four different gray levels from g1 to g4. Even at φ = ±27°, T(g4) > T(g3). This means that at this point an undesirable gray level inversion exists. Fig. 6b shows transmission T as a function of inclination angle θ for φ = 90°. Here a gray level inversion occurs at an angle as small as θ > 12°. Like the gray levels, the contrast of the liquid crystal display is also a function of θ and φ. It is defined as the ratio between the highest and the lowest transmission. Like in the evaluation of gray level inversion, a range of θ can be found for every φ where the contrast is greater than a minimum contrast.

The conoscope diagram (see Fig. 5) illustrates functions θ and φ. Here inclination angle θ and angle φ are represented on a circle, where θ is the radial component and φ is the azimuth. Both the results of the gray level inversion and the contrast values can be plotted in this diagram. A range (cross hatched area in Fig. 5) in which the contrast does not drop below a minimum value (see cross-wise shaded area in Fig. 5) and also where there is no gray level inversion (see Fig. 5, lengthwise shaded area) is defined as a suitable viewing angle range. The boundary line of the contrast area is known as the ISO contrast curve. As Fig. 5 shows, a conventional TN liquid crystal display without any special features has only a very narrow suitable viewing angle range (cross hatched area).

In order to increase this range, different methods can presently be used.

a In European Patent Application No. 646 829 ~~A1~~, the use of a compensation layer is proposed to enlarge the viewing angle range. This layer includes, as an essential component, a discotic retardation film made from a discotic liquid crystal. This is an optically uniaxial film, the regular refraction index $n_o$ being greater than the special refraction index $n_e$. Therefore, the delay $V_R = d_R \cdot (n_e - n_o)$ is negative ($d_R$ being the film thickness). The absolute value of the delay of this film is equal to the delay of the liquid crystal layer, but it has the opposite sign. With the retardation film described in the aforementioned patent application, in addition to

compensating for the birefringence of the material in the liquid crystal, the birefringence caused by the liquid crystal edge molecules on the substrate surface of the liquid crystal cell, which have a certain pre-tilt with respect to the substrate surface, is compensated for. The discotic retardation film must always be adjusted to the orientation of the liquid crystals for a desired compensation effect. If such a film is applied between the cell and the polarization filter, the suitable viewing angle range can be substantially improved.

Another option for improving the suitable viewing angle range is to equalize the asymmetry in the dependence of the contrast on the viewing angle with respect to the dependence of the gray level inversion (see Fig. 5) on the viewing angle. This asymmetry arises due to the asymmetric orientation of the liquid crystal molecules. One method to obtain a symmetric viewing angle range of the liquid crystal cell is to split each pixel into two subpixels having opposite orientations of the liquid crystal molecules, so that the viewing angle range of the first subpixel is rotated with respect to that of the second subpixel by 180° (Fig. 7, Two-domain ~~method~~, K.H. Yang: Record 1991 Int. Display Res. Conf., San Diego, California). Thus the asymmetric viewing angle ranges of the subpixels supplement each other to form a relatively small, however, essentially point-symmetric viewing angle range (see Fig. 8). An additional increase in this viewing angle range using a compensation film, as disclosed in European Patent Application No. 646 829 ~~A1~~ is not feasible, since the discotic layer is adjusted to a certain orientation of the liquid crystal and thus only one subpixel can be compensated for at a time.

An alternative option is to subdivide a pixel into four subpixels (4-domain method). In this case, each subpixel has a different orientation in that, for example, on a substrate side with diagonally adjacent subpixel ranges, the liquid crystal edge molecules are oriented with a 180° offset (see Fig. 10). The technological complexity using the 4-domain method is considerably higher than with the 2-domain method; however, a relatively larger suitable viewing angle range is achieved (see Fig. 11).

Also with this method, no improvement occurs in the suitable viewing angle range due to the above-described compensation layer for the reasons presented previously.

~~The~~ An object of the present invention is to provide a liquid crystal display having as large a viewing angle range as possible, in which no gray level inversion takes place and the contrast is greater than a minimum value (e.g., 10).

~~This object is achieved by the features of Claim 1.~~

Advantageous and suitable refinements of the liquid crystal display according to the present invention are presented in the subclaims.

The present invention is based on a liquid crystal display having a plurality of pixels, which includes a liquid crystal cell and polarizers that are arranged on the top and bottom of the liquid crystal cell, the liquid crystal cell including two substrates with transparent electrodes and a liquid crystal sandwiched therebetween. The core of the present invention is that each pixel is subdivided into at least two subpixels, in which the liquid crystal has different orientations and that an optically biaxial retardation film with different refraction indices $n_e$, $n_o$, $n_z$ is provided at least between a polarizer and the liquid crystal in order to compensate for the dependence of the optical properties of the liquid crystal display, such as, for example, transmission and contrast, on the viewing angle, the refraction index $n_z$ being measured in the retardation film along an axis that is essentially parallel to the normal to the liquid crystal cell. Thus the advantages of a multidomain method can be combined with those of a layer that compensates for the birefringence in the liquid crystal cell. In particular, due to the optical biaxiality, the refraction characteristics of the liquid crystal molecules opposite the substrate surface in the liquid crystal cell can be compensated for as desired, in particular, achieving an especially effective compensation. While the basic orientation of the liquid crystal molecules should be taken into account, an orientation of the liquid crystal molecules offset by 180° is, however, allowable, which ultimately allows the use of a retardation film for differently oriented subpixels. In addition, the retardation film according to the present invention, in combination with the multidomain method, in particular when the liquid crystal molecules are oriented due to the exposure of a photosensitive layer, represents a cost-effective alternative to relatively similarly effective compensation layers (e.g., discotic retardation films).

In order to achieve a particularly effective compensation of the viewing angle dependencies, it is furthermore proposed that the refraction indices $n_e$, $n_o$, $n_z$ of the biaxial retardation film be dimensioned so that $n_e - n_o > 0$ and $n_z - n_o < 0$.

In order to achieve a relatively simple design of the liquid crystal display, it is furthermore proposed that the retardation film be arranged on the liquid crystal cell between the polarizer and the liquid crystal cell.

For a particularly compact design it is advantageous if the retardation film in the liquid crystal cell is arranged between the liquid crystal and the substrate.

A particularly simple and compact design is achieved when the substrate itself forms the retardation film (plastic substrate with a suitable delay).

In order to provide a high degree of symmetry, it is also proposed that the retardation film be arranged on both sides between the liquid crystal and the polarizers.

For a retardation film applied on both sides, it is advantageous if the layer meets the following dimensioning specifications:

70 nm < $(n_e - n_0)\cdot d$ < 200 nm and $-200\,nm < (n_z - n_o)\cdot d$, $\cancel{200\,nm < (n_z - n_o)}$, where d is the thickness of the retardation film. If the retardation film is only on one side, basically the same values given in nm can be used without any considerable deterioration in the compensation effect.

In a particularly advantageous embodiment, one or more plastic films are used as the retardation film. For example, a retardation film made of a unidirectional plastic film can be used, which however, is not stretched to saturation. The use of a retardation film made of a bidirectionally stretched plastic film is also possible. Finally, a combination of one or more uniaxially positive and one or more uniaxially negative films is also possible. Retardation films have the advantage that they can be applied in a simple manner, for example, by laminating.

The retardation film can also be implemented using a holographic element or in the form of a liquid crystal polymer.

It is particularly advantageous if the subpixels of a ~~liquid crystal~~ pixel of the liquid crystal are oriented so that the viewing angle ranges of the individual subpixels supplement one another. For a TN liquid crystal cell with pixels subdivided into two subpixels, this can be implemented by

the angles of the liquid crystal edge molecules of the subpixels on the base substrate being of opposite orientations;

the angles of the liquid crystal edge molecules of the subpixels on the cover substrate being of opposite orientations;

the angles of the liquid crystal edge molecules of the subpixels on both substrates being of opposite orientations;

the angles of orientation of the liquid crystal edge molecules of the subpixels on the base substrate being of different magnitudes;

the angles of orientation of the liquid crystal edge molecules of the subpixels on the cover substrate being of different magnitudes; or

the angles of orientation of the liquid crystal edge molecules of the subpixels on the base and cover substrates being of different magnitudes.

The twist of the TN cells may amount to between 80° and 100°.

The liquid metal molecules on the substrate surfaces can be orientated by mechanical rubbing or via an orientation layer.

In a particularly preferred embodiment, a photosensitive film is used to orient the liquid crystal molecules on the substrate surfaces; the preferential direction of orientation of the liquid crystal molecules is determined by exposure to light.

In order to achieve a high contrast, it is also proposed that the boundary areas between the subpixels be covered by a mask.

In an advantageous embodiment, each pixel has a switch element such as a thin-layer transistor, a thin-layer diode or a metal-insulator-metal-diode.

In another advantageous embodiment, a thin-layer transistor and a reservoir capacitor is arranged in each pixel; at least one electrode of the reservoir capacitor is implemented using a conductive, non-transparent layer, which covers the boundary area between the subpixels. In this manner, the boundary area between the pixels is covered while the aperture of the liquid crystal display remains constant.

Brief Description of the Drawings

Different embodiments of the present invention are illustrated in the drawings and described in detail in the description that follows.

Figure 1 schematically shows the design of a liquid crystal display according to the present invention;

Figure 2 shows the alignment of the indices of refraction in a retardation film according to the present invention having two optical axes;

Figures 3a, b schematically show the design of a conventional twisted nematic liquid crystal display;

Figure 4 shows a model for representing the coordinates for determining the viewing angle;

Figure 5 illustrates the dependence of contrast and gray scale level on the viewing angle in a conventional nematic liquid crystal display;

Figures 6a, b show the variation of transmission as a function of the angle of inclination θ for different gray scale settings;

Figure 7 schematically shows the orientation of the liquid crystal edge molecules for a pixel divided into two subpixels;

Figure 8 shows the dependence of contrast and gray scale inversion on the viewing angle for one orientation of the liquid crystal molecules according to Fig. 7 without retardation film;

Figure 9 shows the dependence of contrast and gray scale inversion for an arrangement according to Fig. 7 with a biaxial retardation film according to the present invention;

Figure 10 shows the orientation of the liquid crystal edge molecules on the base substrate and the cover substrate with the pixel being divided into four subpixels;

Figure 11 shows the diagram for Fig. 10 for the dependence of contrast and gray scale inversion on the viewing angle without a retardation film; and

Figure 12 shows the diagram for Fig. 10 for the dependence of contrast and gray scale inversion on the viewing angle with the optically biaxial retardation film ~~according to the present invention.~~

~~Detailed Description~~

As mentioned above ~~in the preamble of the description,~~ the embodiments are described on the basis of a conventional twisted nematic liquid crystal display according to Figs. 3a and 3b. A liquid crystal, twisted by 90°, is sandwiched between glass substrates 1, 2; its elongated liquid crystal molecules are represented by rods 3. A polarizer 4, 5 is mounted on each glass substrate. The transmission direction of the polarizers (indicated by a double arrow) is the same as the orientation of the longitudinal axis of the liquid crystal molecules, but it may also be oriented 90° to that direction. Fig. 3a shows the no-voltage state in which the penetrating light (indicated by the wide arrow) is twisted by 90° due to the liquid crystal helix and then

can exit polarizer 5 unimpeded. The cell is transparent and appears light-colored. When a voltage is applied, the liquid crystal molecules become oriented by their dielectric anisotropy in the electric field, whereby the light (represented by a wide arrow in Fig. 3b) penetrating from below passes through the liquid crystal cell unimpeded and is then absorbed by polarizer 5. In this state, the liquid crystal cell appears dark-colored.

One undesired liquid crystal cell effect is dependence, in particular, of gray levels and contrast on the viewing angle. To determine the viewing angle, the coordinates shown in Fig. 4 are introduced. Angle φ located in the plane of the substrate, may vary from 0° to 360°, while angle θ measures the inclination with respect to the normal to the liquid crystal (z). For Figs. 5, 6a and 6b, reference is made to the preamble to the description. Subject to improvement is the cross hatched area of a conventional TN cell, which can be considered a suitable viewing angle range.

For this purpose, a liquid crystal display designed according to the present invention according to Fig. 1 is used. A liquid crystal is placed between a base substrate (GS) and a cover substrate (DS); the longitudinal axes of its liquid crystal edge molecules are oriented according to the arrows on the base and cover substrate. A retardation film V1, V2 is arranged on the top and bottom of the base and cover substrates. The extraordinary axis ($n_e$) in the retardation film is denoted by arrows; it extends perpendicular to the orientation of the liquid crystal molecules on the corresponding adjacent substrate (see Fig. 2 for the position of the other optical axes in the retardation film). Finally, a polarization filter P1 and P2 is installed on retardation films V1 and V2, respectively; the absorbing axes of these filters are parallel to the orientation of the liquid crystal molecules for the corresponding adjacent substrate (broken-line double arrow). In addition to a strong perpendicular or parallel orientation between the given directions, the projection of the extraordinary axis of the liquid crystal edge molecules may form an angle from 0° to 5° with the absorbing axis of the polarizer for the base and cover substrate, and the extraordinary axis of the retardation film may form an angle of 85° to 90° with the absorbing axis of the polarizer.

According to the present invention, a pixel is to be divided into subpixels according to Fig. 7

with adjacent subpixels 6, 7 being oriented in 180° opposite directions as shown by the symbolic representation of longitudinal axis 8 of the molecules. Such an orientation results in an essentially point-symmetric variation of the gray level inversion and the border line for a surface in which the contrast does not drop below a minimum (see Fig. 8). The area in which no gray level inversion occurs is represented in Fig. 8 by crosses, while the isocontrast curve for a minimum contrast of 10 is represented by squares.

The individual areas, but especially the section area where the contrast does not drop below a minimum value and no gray level inversion occurs are considerably increased by the additional use of a retardation film according to the present invention (see Fig. 9).

An even better initial situation with regard to the dependence of contrast and gray level inversion on the viewing angle is achieved by dividing a pixel into four subpixels according to Fig. 10. As a result of the orientation of longitudinal axes 8 of the molecules as illustrated in Fig. 10, different liquid crystal orientations are obtained for all four subpixels. The symmetry and dependence on the viewing angle are thus improved, but especially the section surface in which the contrast does not drop below a minimum and no gray level inversion occurs is considerably enlarged. If the retardation film with two optical axes according to the present invention is also used, an even more improved contrast and gray level inversion situation is achieved, as shown in the diagram of Fig. 12. Up to an inclination angle θ of approximately 65°, the contrast at no point drops below a minimum, which is 10 in this embodiment. Also, up to an inclination angle θ of approximately 65°, no gray level inversion takes place.

The biaxial retardation film thus makes it possible to manufacture liquid crystal displays that allow excellent viewing angle dependence by the additional use of the "multidomain method."